Jet Propulsion Laboratory
California Institute of Technology

Remote sensing of Earth from space

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Science Division/Science Data Understanding group

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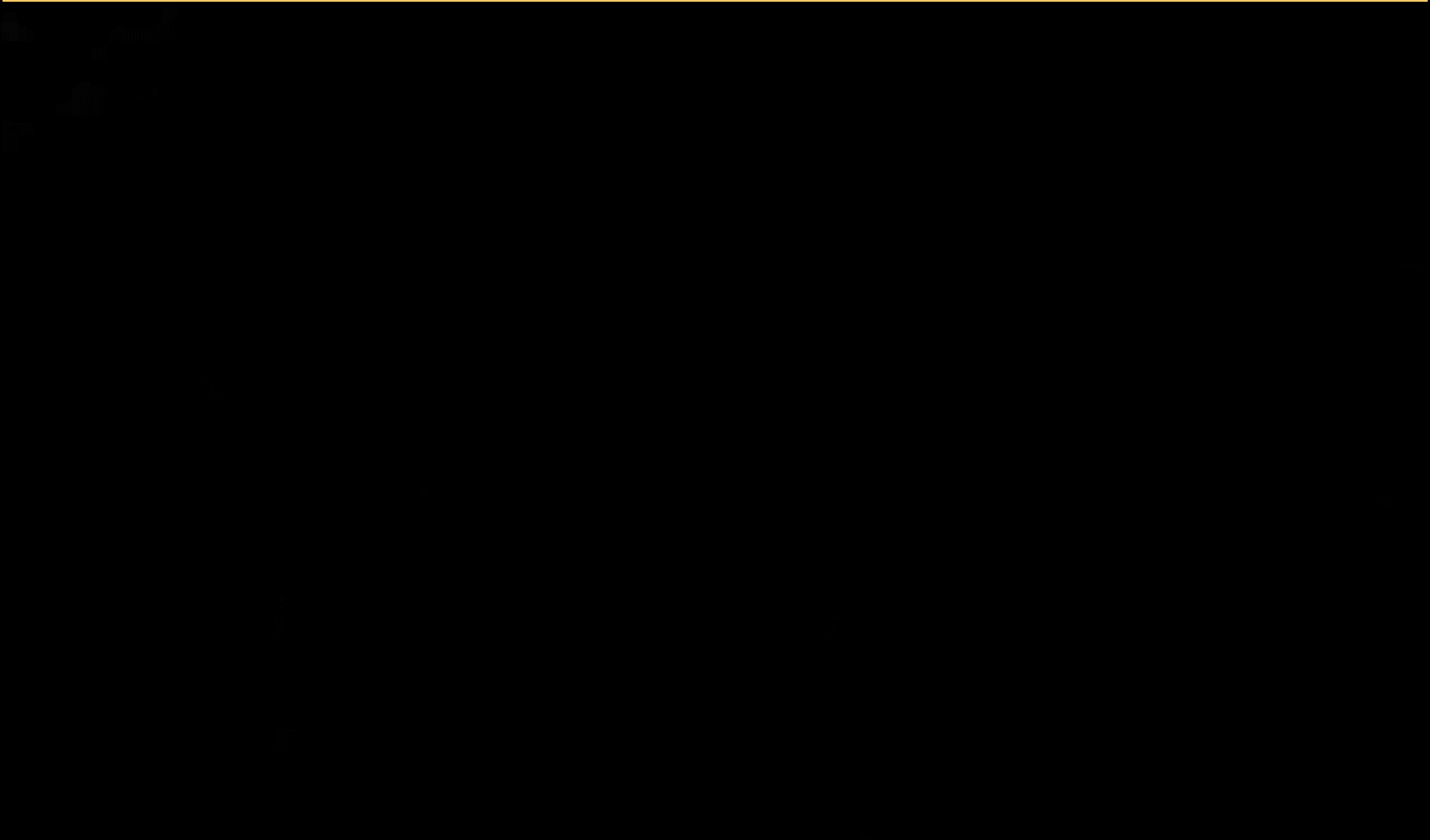
Von Karman museum

Assembly Area – Clean Room

Mission control center

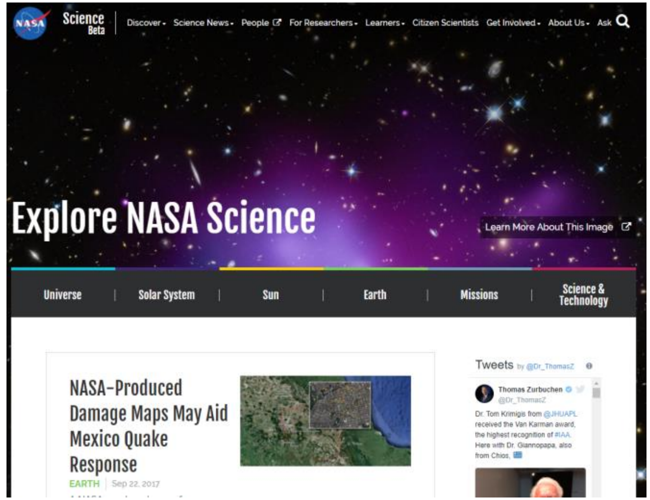
Curiosity Rover

Curiosity Rover's Landing on Mars



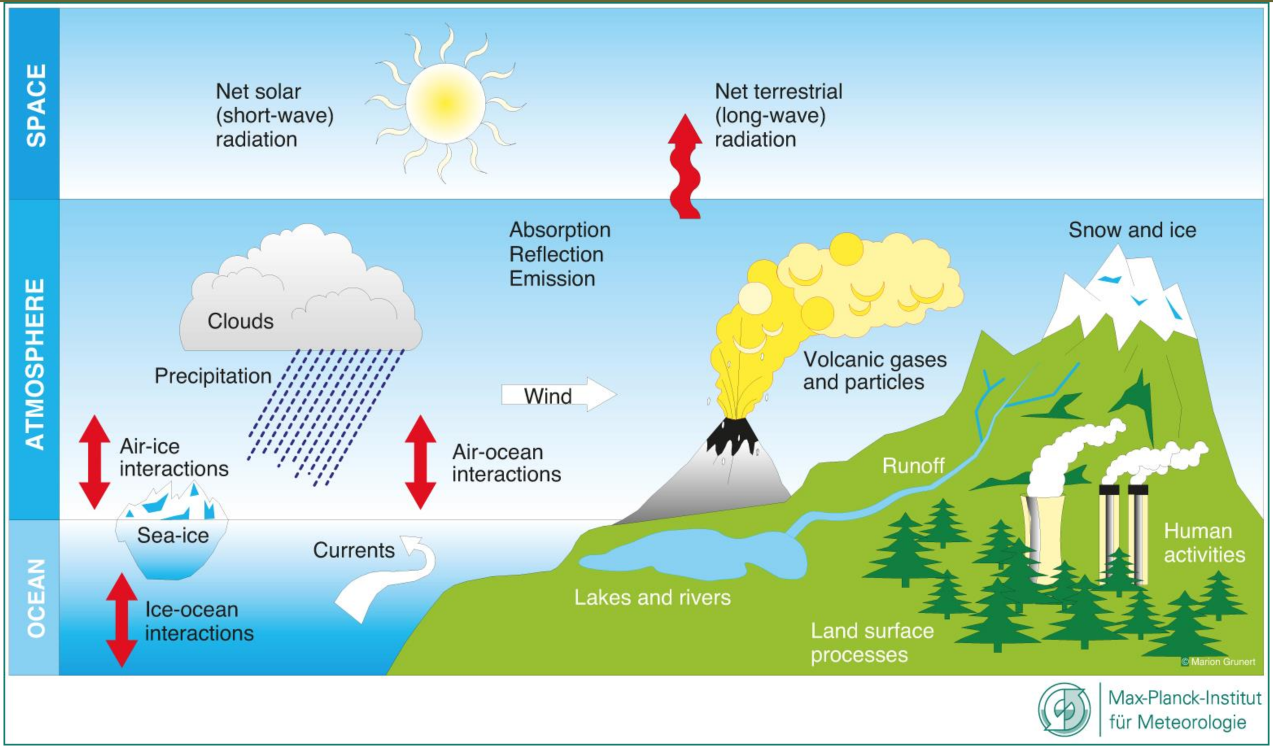
NASA Earth Science

- https://science.nasa.gov



- There are four science divisions
  - **Earth Science**
  - Astrophysics
  - Heliophysics
  - Planetary science
- Fundamental Earth Science questions
  - How is the global Earth system changing?
  - What causes these changes in the Earth system?
  - How will the Earth system change in the future?
  - How can Earth system science provide societal benefit?

Earth's climate system



Climate forcings:

- natural – solar radiation, volcanic eruptions, ocean circulation changes
- anthropogenic – greenhouse gases, aerosols and clouds, stratospheric ozone, land-surface changes

Earth Science research at NASA

- Earth scientists at NASA study the atmosphere, land, and oceans on Earth to make better predictions of future changes using observations.

- Water and carbon cycles: rain, water vapor, ground water, soil moisture, carbon dioxide, vegetation, and so on.
- Oceanography: sea surface temperature, topography of the ocean surface, salinity, wind fields near the ocean surface, sea ice, and so on.
- Atmospheric science: temperature, water vapor, winds, atmospheric composition changes, clouds, aerosols, lightning, ….

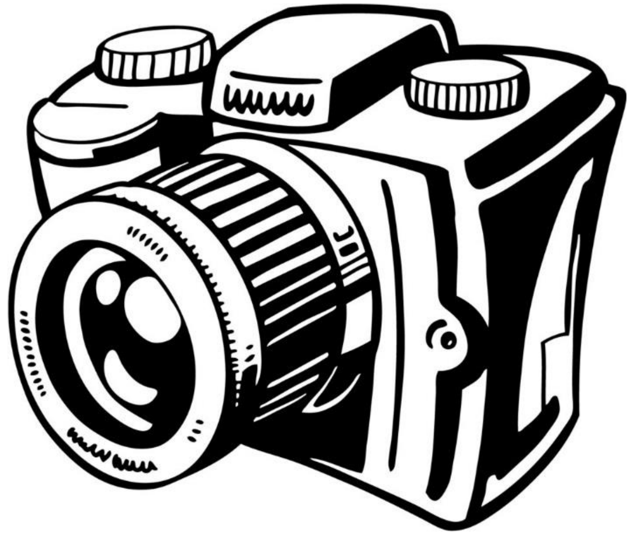
Earth Science Missions

Remote sensing

- "Remote sensing is the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites". (https://oceanservice.noaa.gov/facts/remotesensing.html)

Laser thermometer (https://sciencing.com/laser-thermometers-work-4962575.html)

Camera



Near Sydney, Australia (Oct. 23, 2013)

(https://www.nasa.gov/mission_pages/station/research/benefits/remote_sensing)

How to design a satellite mission?

- What do we want to observe?

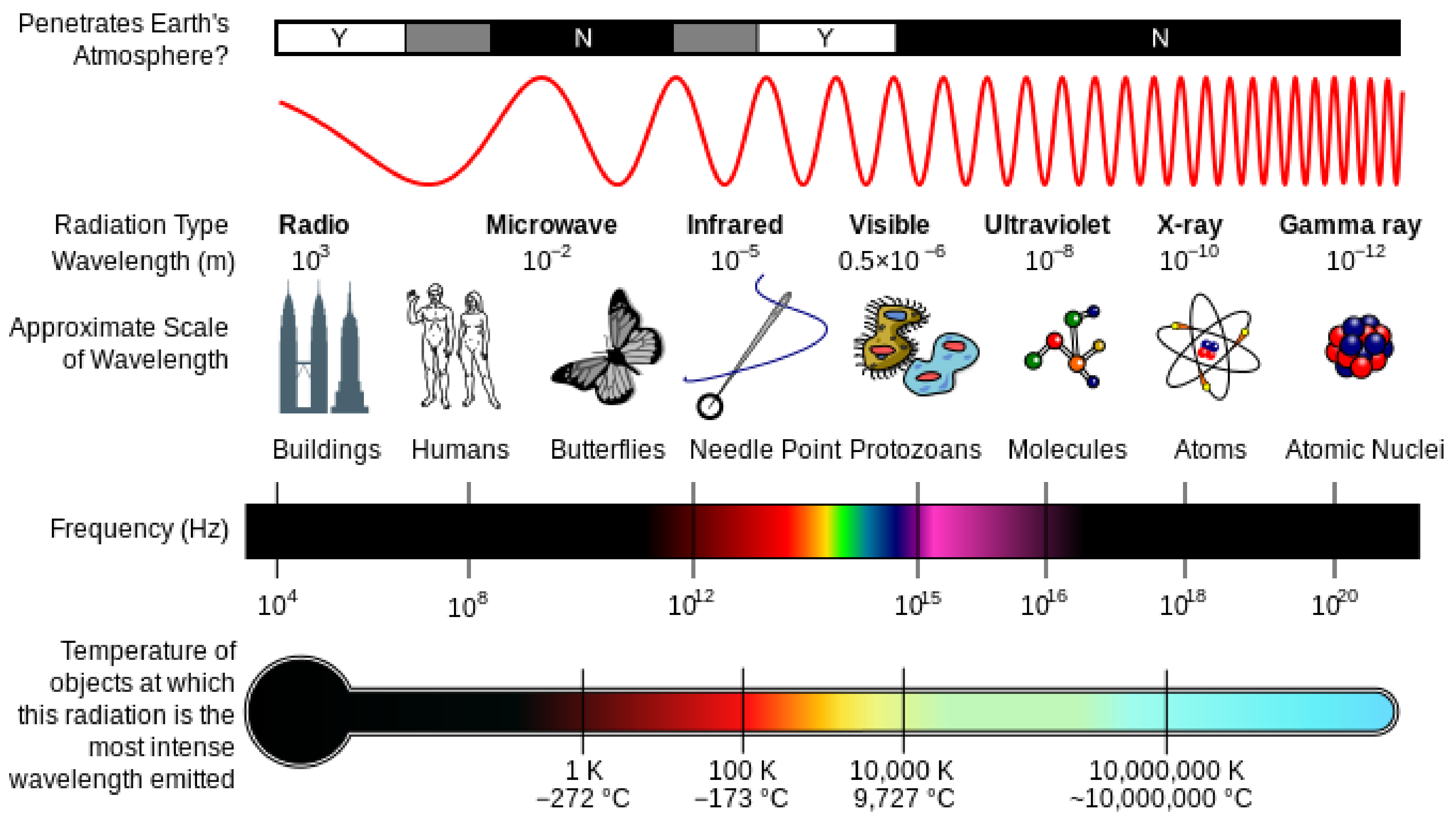
(ex) rain, water vapor, ground water, soil moisture, carbon dioxide, vegetation, sea surface temperature, topography of the ocean surface, salinity, wind fields near the ocean surface, sea ice, temperature, water vapor, winds, ozone, clouds, aerosols, lightning)

- Electromagnetic spectrum

- Active vs Passive sensors

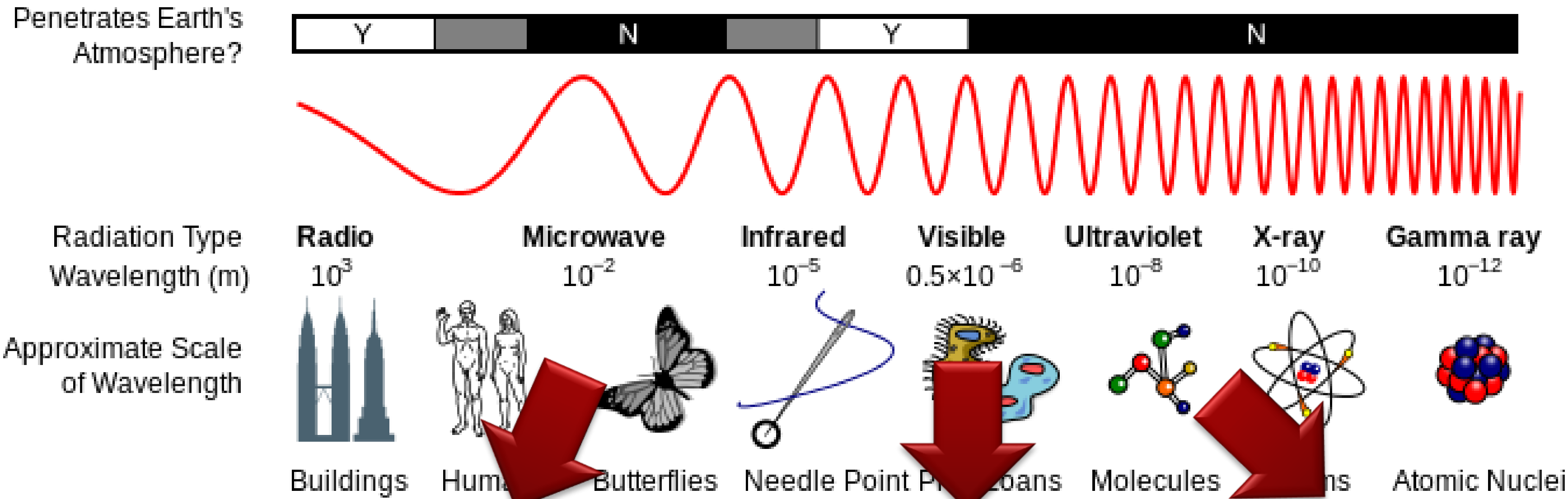
- High vs Low orbits

Electromagnetic spectrum



https://en.wikipedia.org/wiki/Electromagnetic_spectrum#/media/File:EM_Spectrum_Properties_edit.svg

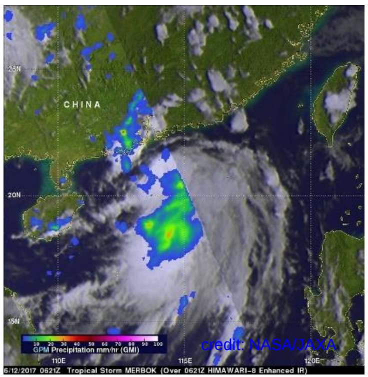
Examples

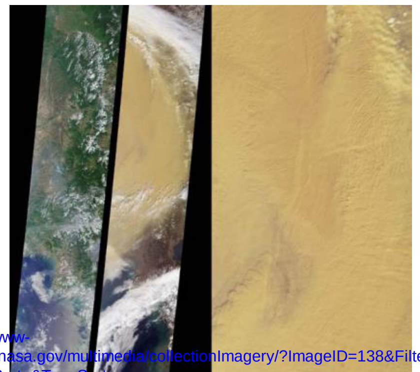


Tropical storm in Southern China Sea

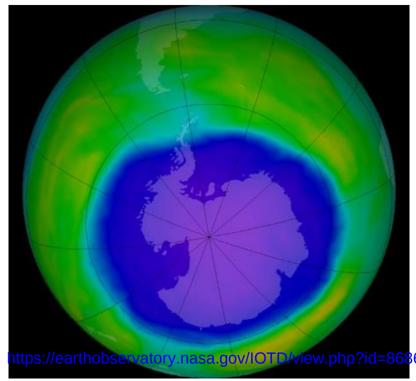
Yellow sand

Antarctic ozone hole in 2015





https://www-misr.jpl.nasa.gov/multimedia/collectionImagery/?ImageID=138&Filter=Off&ThemeSort=&TypeSort=

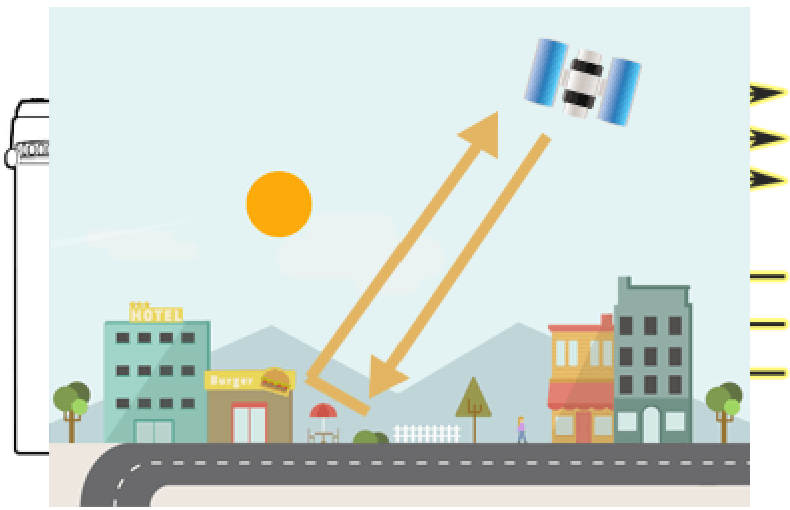


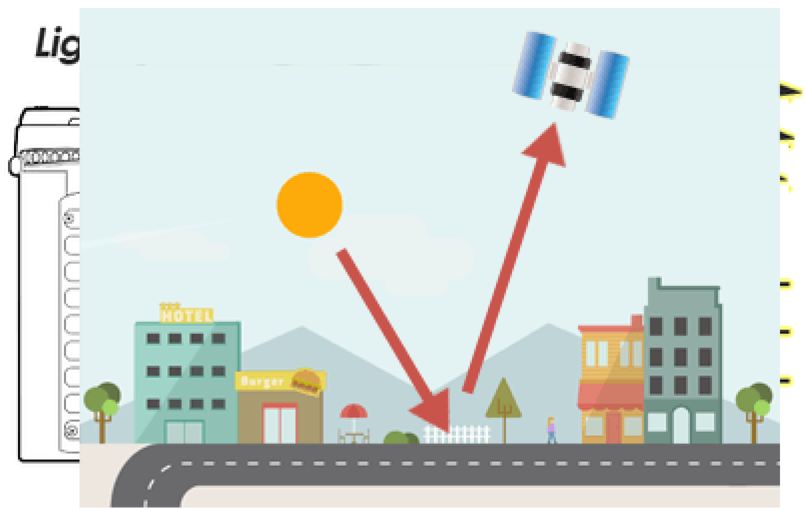
https://earthobservatory.nasa.gov/IOTD/view.php?id=86869

Active vs Passive sensors in remote sensing

(http://gisgeography.com/passive-active-sensors-remote-sensing/)

- Active sensors emit radiation and measure the radiation that is reflected or backscattered from the target.
- Passive sensors detect radiation that is emitted or reflected sunlight by the target.

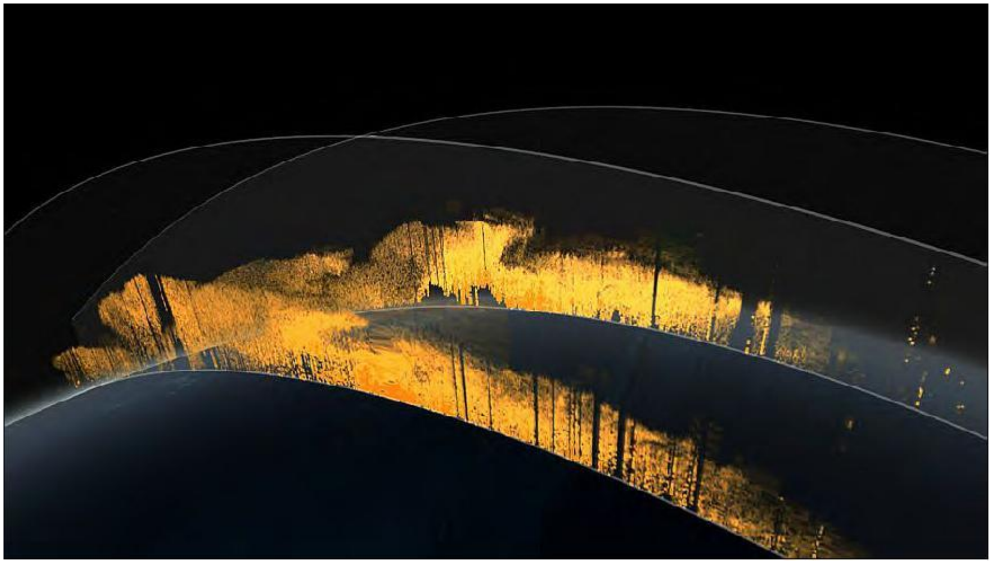




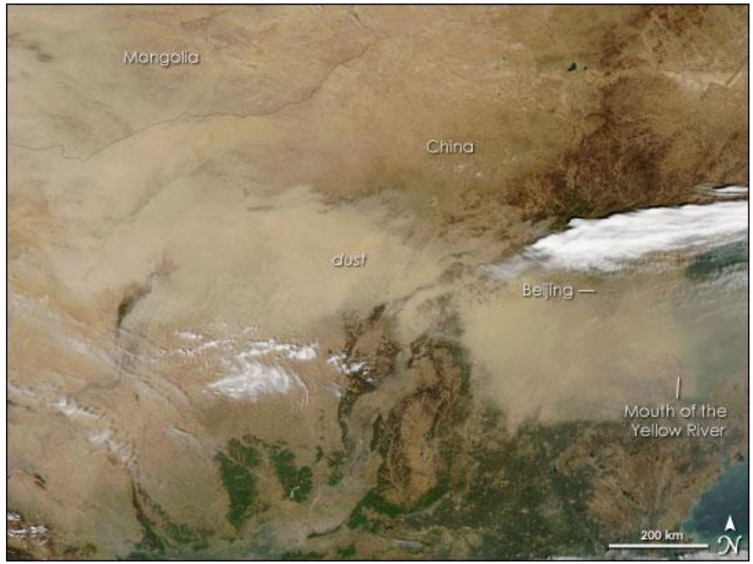
images from (http://gisgeography.com/passive-active-sensors-remote-sensing/)

Example: active vs passive infrared sensors

- Active sensor: CALIOP (Cloud-Aerosol LIdar with Orthogonal Polarization)
- Passive sensor: MODIS (Moderate Resolution Imaging Spectroradiometer)



images from (https://events.eoportal.org/web/eoportal/events/event-details/-/article/calipso)

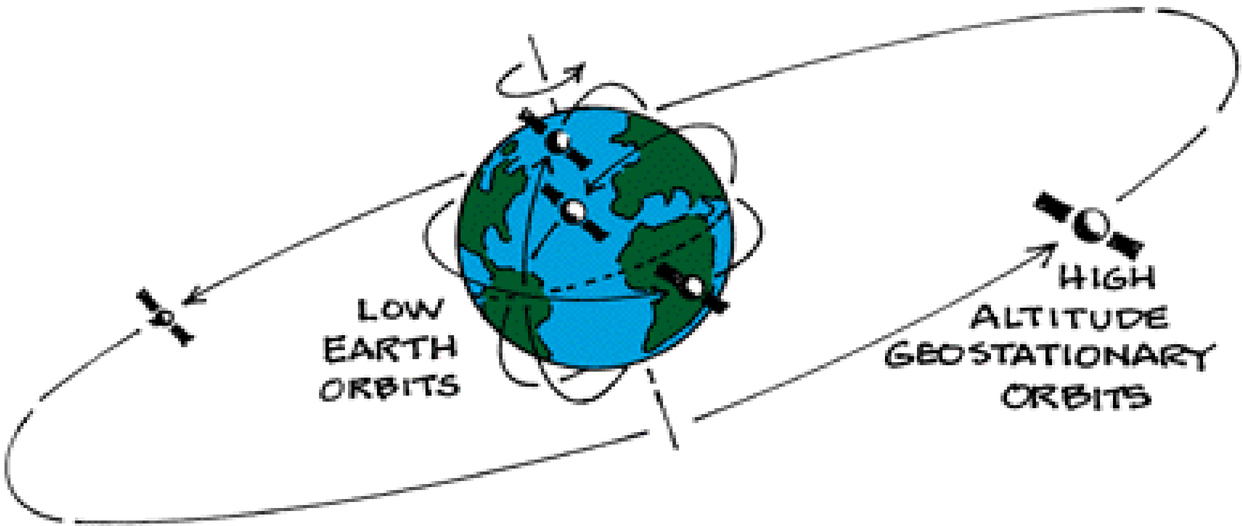


images from (https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=14861)

High vs Low orbits

(http://gisgeography.com/passive-active-sensors-remote-sensing/)

- High altitude (35,786km) geosynchronous orbit: constant view of a given location
- Low altitude (hundreds – thousands km) polar and sun synchronous orbit: the time of observation is the same for a given location



images from (http://paos.colorado.edu/~fasullo/1060/resources/satellites.html)

Example: high vs low orbit satellites

- Geostationary orbit: weather satellites, 천리안위성(Communication, Ocean and Meteorological Satellite, COMS)

- Low orbit: CYGNSS (Cyclone Global Navigation Satellite System)

How to obtain information from satellite observations?

NASA: Product Level Guide

L4: Model output; derived variables

L3: Gridded and quality controlled

L2: Products derived from L1B

L1B: Geolocated and calibrated

L1A: Reconstructed, raw instrument data

L0: Raw instrument data

https://climatedataguide.ucar.edu/climate-data/nasa-satellite-product-levels

- Photo: L1B
- Fire pixels: L2

Inversion methods

http://www.stevebloom.com/index.php?page=single&id=002985-SB1

- Footprints in snow (L1B data)
- Our prior knowledge
  - Footprints are darker
  - Each animal leaves its own footprints
- Using the L1B data,
  1. Detect locations of footprints
  2. Identify animal footprints
  3. Bear footprints are observed (L2 data)

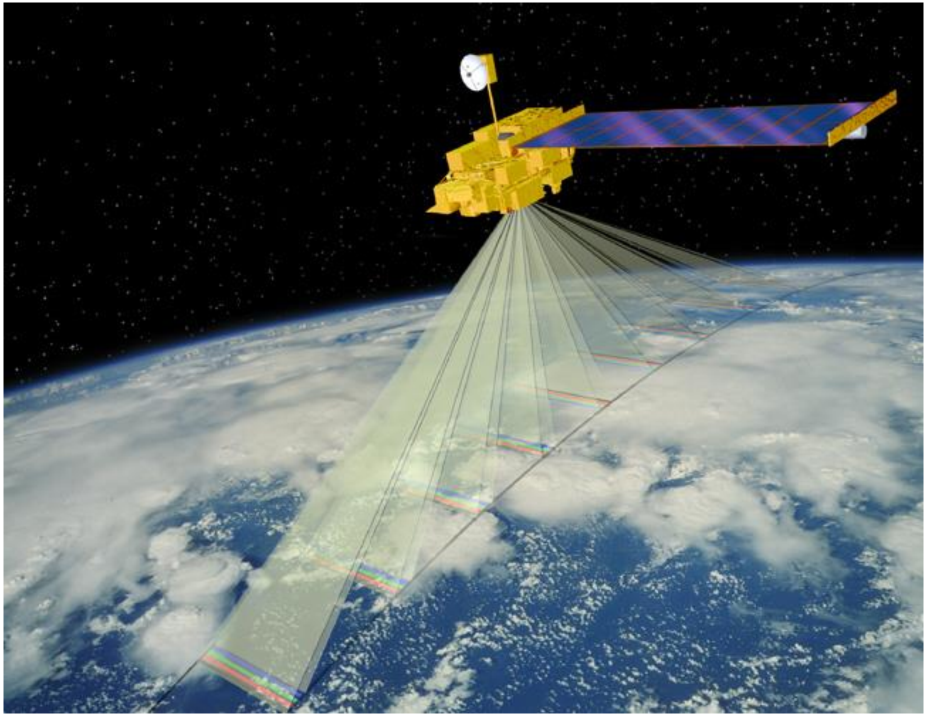
Inversion methods in Earth remote sensing

- An astronaut's photo (L1B)
- Our prior knowledge
  - Flames are bright
  - The color difference between artificial light and flames
  - Wildfires induce smoke plumes
- Areas of wildfires and plumes (L2)

NASA Terra Satellite [March 2000 – present]

courtesy of Prof. Di Girolamo at Univ. of Illinois

Multi-angle Imaging SpectroRadiometer (MISR)



Nine view angles at Earth surface:
70.5º forward to 70.5º backward

Nine 14-bit pushbroom cameras

275 m - 1.1 km sampling

Four spectral bands at each angle:
446, 558, 672, 866 nm

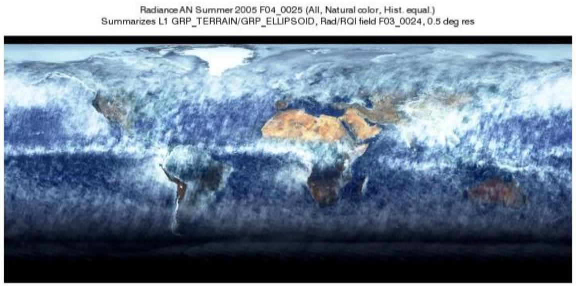
400-km swath: 9-day coverage
at equator, 2-day at poles

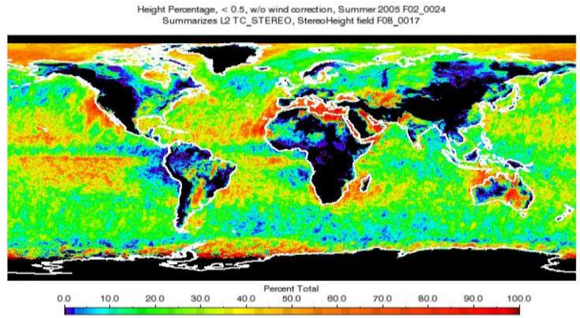
7 minutes to observe each scene
at all nine angles

courtesy of Michael Garay at JPL

Example MISR Standard Products

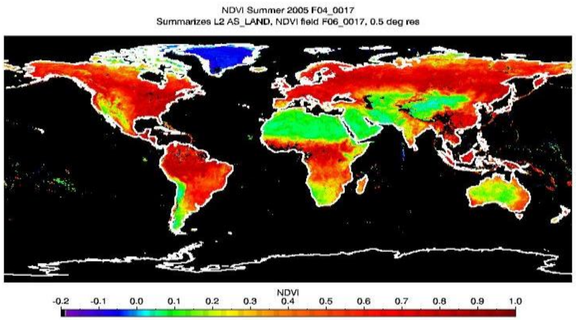
Radiance

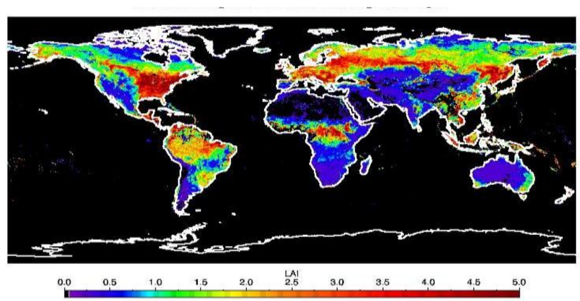




Cloud Top Height

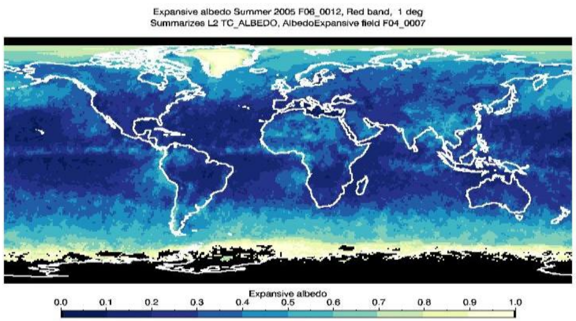
NDVI (normalized difference vegetation index)

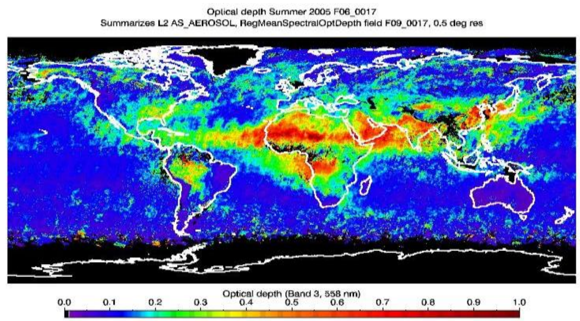




LAI (leaf area index)

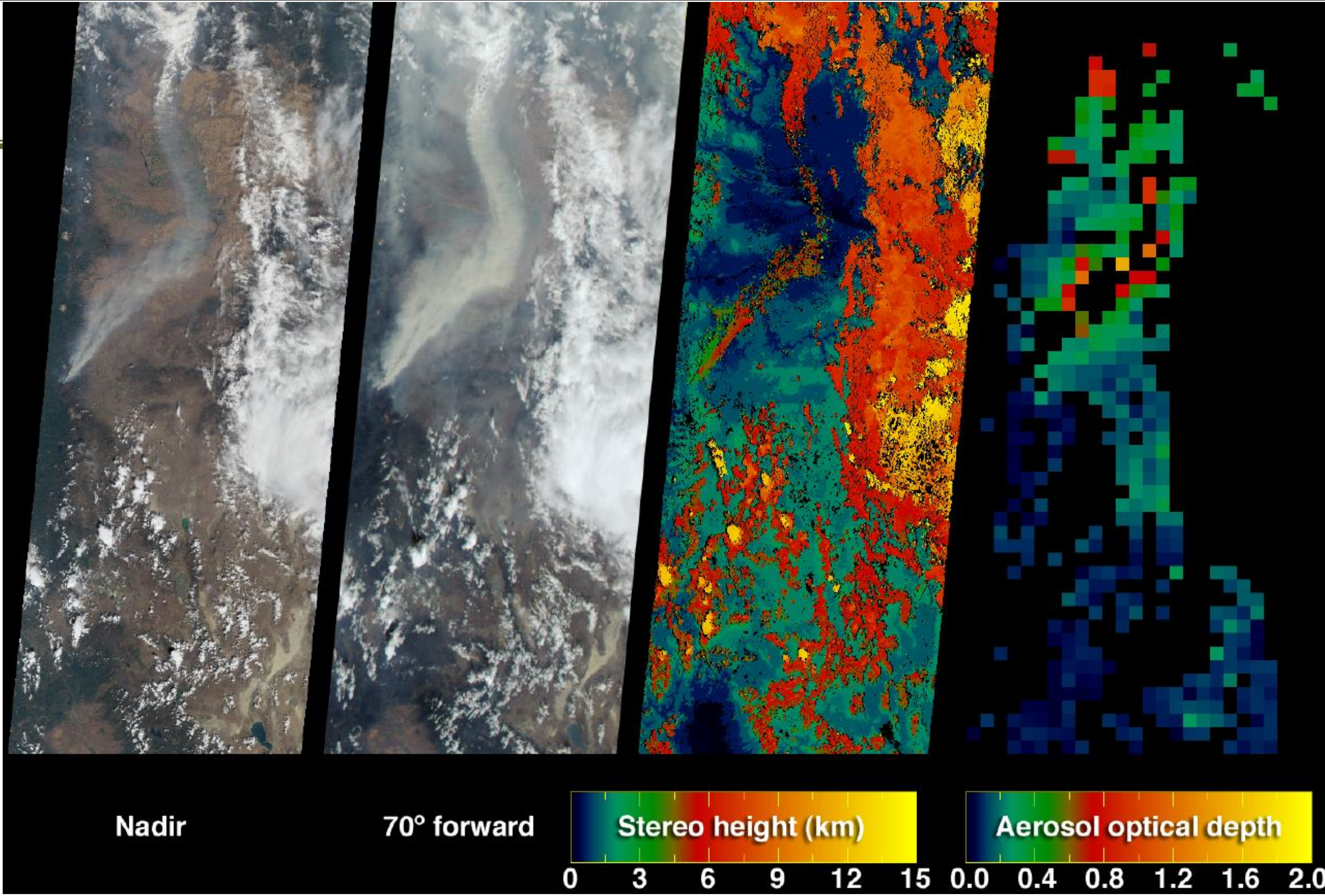
Albedo





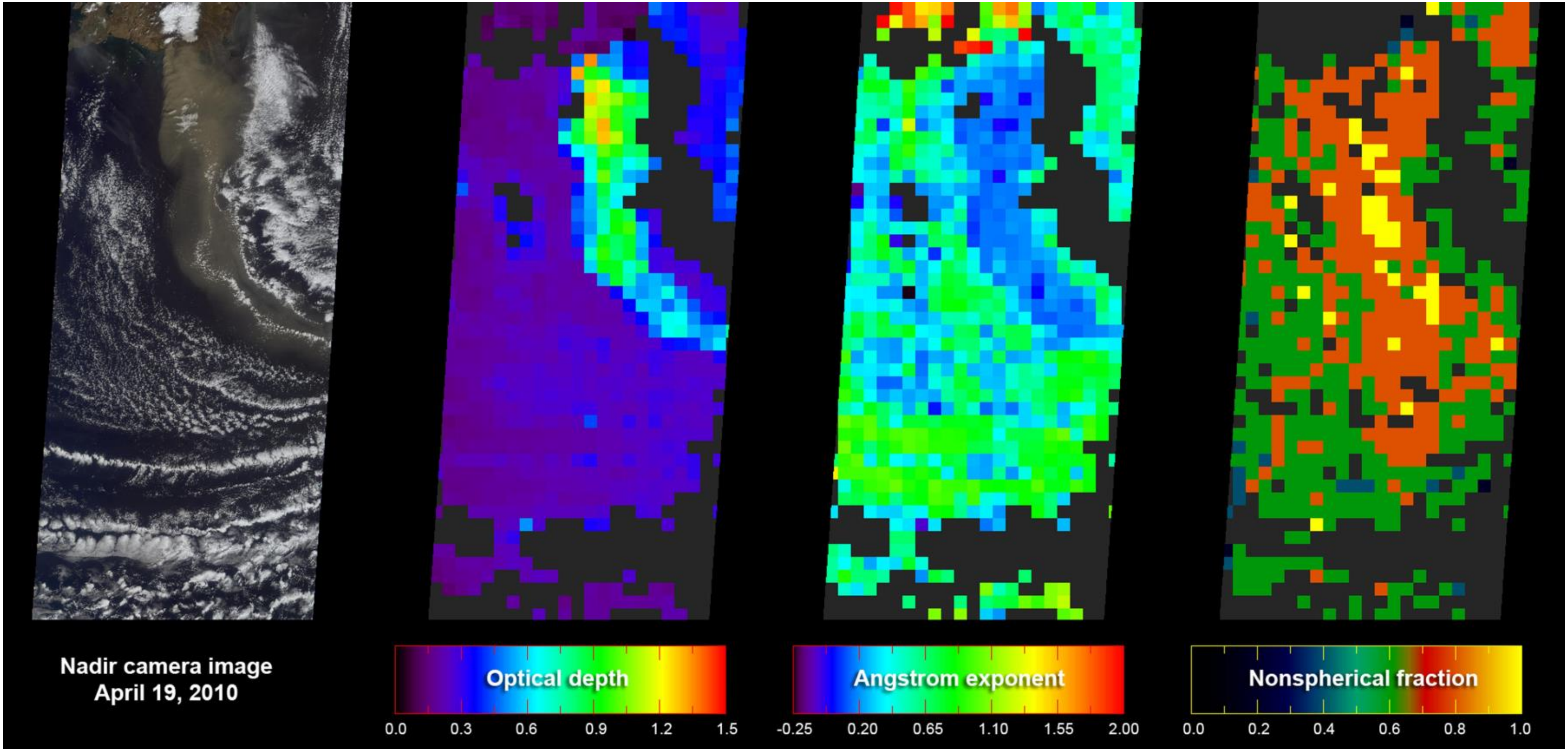
AOD (aerosol optical depth)

courtesy of Michael Garay at JPL



courtesy of Michael Garay at JPL

Aerosol particle properties from MISR



MISR views of Eyjafjallajökull – 4/19/2010

courtesy of Michael Garay at JPL

A decadal (2018-2027) strategy for Earth Observation from Space by the National Academies of Sciences

Recommended NASA Priorities: Designated

http://sites.nationalacademies.org/cs/groups/depssite/documents/webpage/deps_183919.pdf

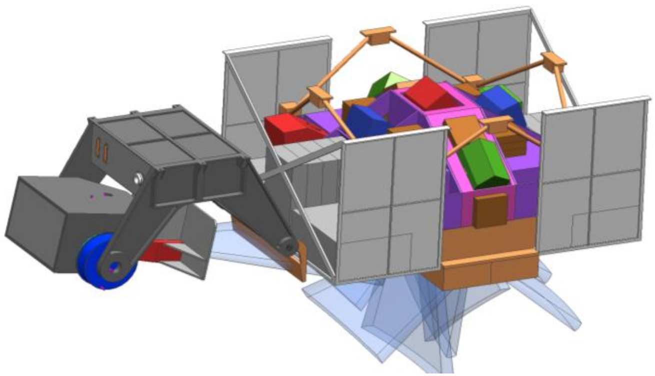
TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, & Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		

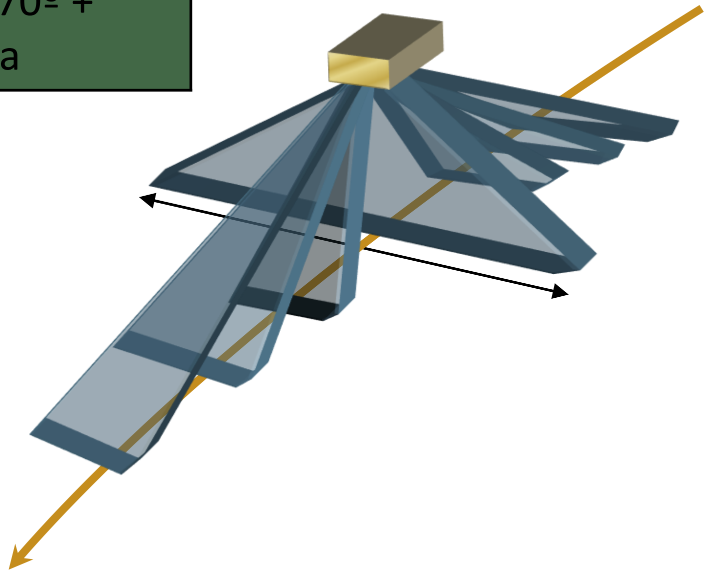
- Three tiers in the recommended NASA priorities:

  Designated > Explorer > Incubation

Multiangle SpectroPolarimetric Imager (MSPI)

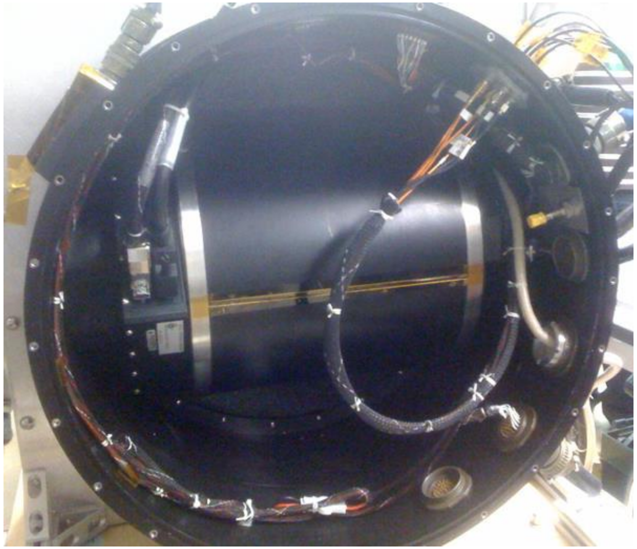
MISR	MSPI
9 cameras, 4 VNIR bands	9 cameras, UV-VNIR-SWIR bands Polarimetry in selected bands
View angles (9): Nadir, 26º, 46º, 60º, 70º	Fixed view angles (7): Nadir, 38º, 60º, 70º + gimbaled camera

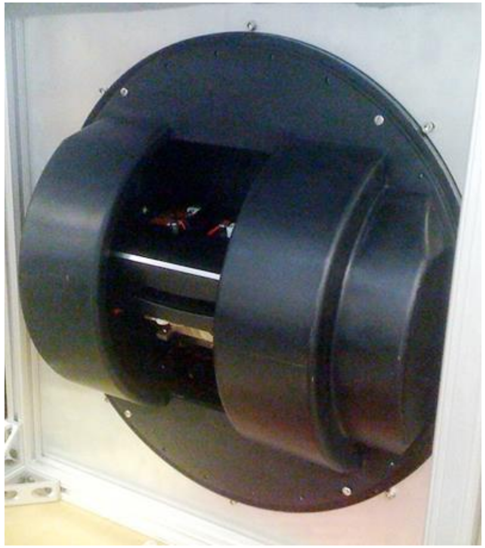




courtesy of Michael Garay at JPL

Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)





Spectral bands: 355, 380, 445, 470*, 555, 660*, 865*, 935 nm (*polarimetric)

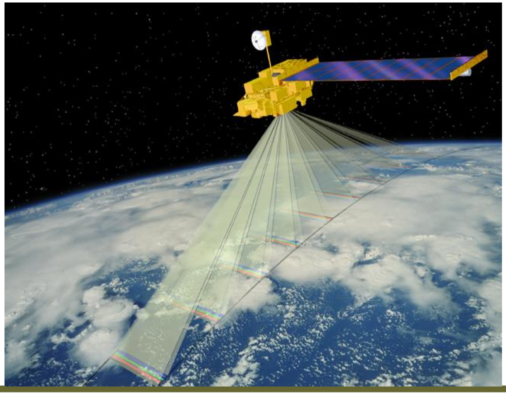
courtesy of Michael Garay at JPL

Flies in nose of NASA ER-2

Has flown: Oct 2010, Aug/Sep 2011, Jan 2012, Jul/Aug 2012, Jan/Feb 2013 (PODEX), May 2013, Aug/Sept 2013 (SEAC^{4}RS), Oct 2013

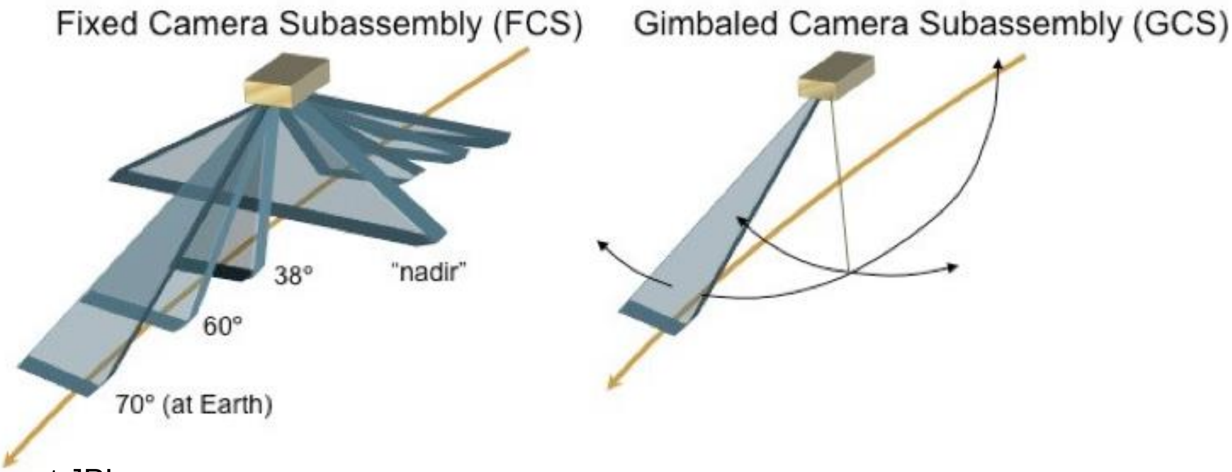
Evolution from MISR to AirMSPI

Capability	Purpose	MISR	AirMSPI
UV bands	Aerosol height, aerosol absorption	Not included	365, 380 nm
VNIR bands	Fine mode aerosols, land and ocean surface	446, 558, 672, 866 nm	445, 470*, 555, 660*, 865*, 935 nm
SWIR bands	Coarse mode aerosol, clouds, atmospheric correction	Not included	Not included
Multiangle views	Aerosols, albedo, texture	0º-70º views, 9 angles	0º-70º views with gimbaled camera
Polarimetry	Aerosol refractive index, surface texture and orientation	Not included	0.5% DOLP tolerance
Spatial resolution	Scene classification, stereo	275 m – 1.1 km	10 m – 25 m



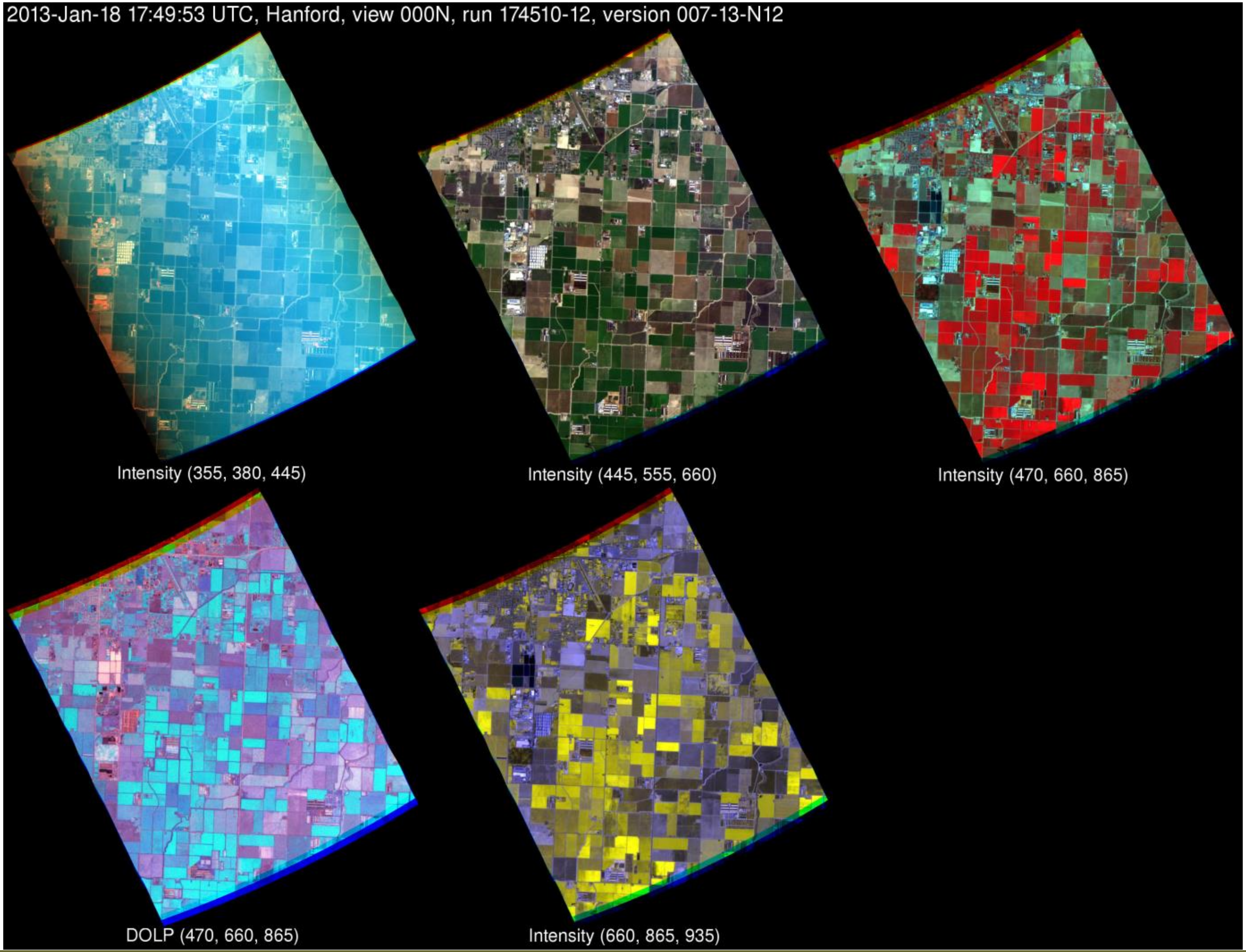
courtesy of Michael Garay at JPL

Example Sampling Strategy



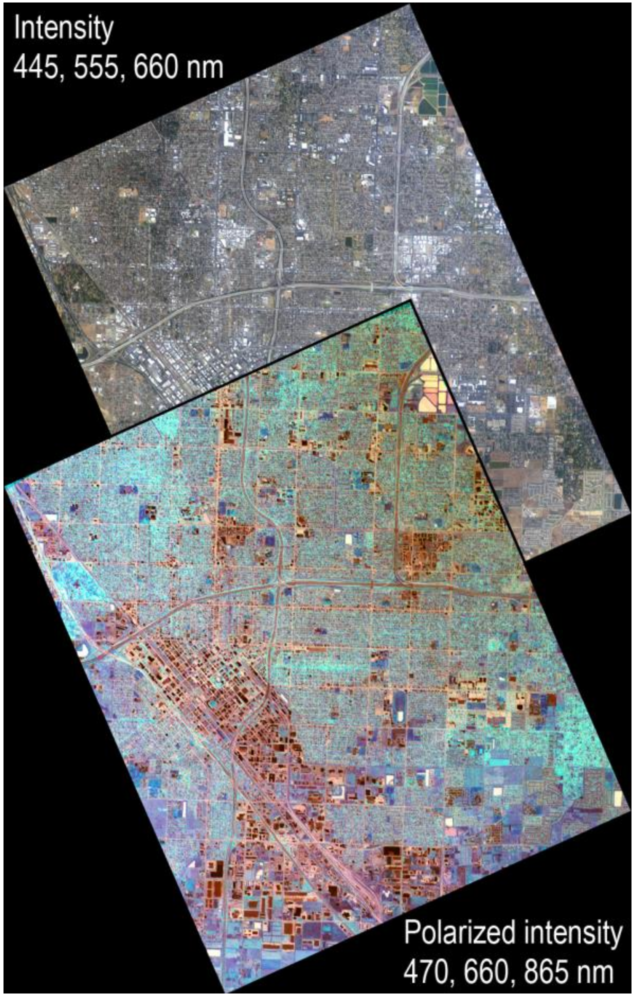
courtesy of Michael Garay at JPL

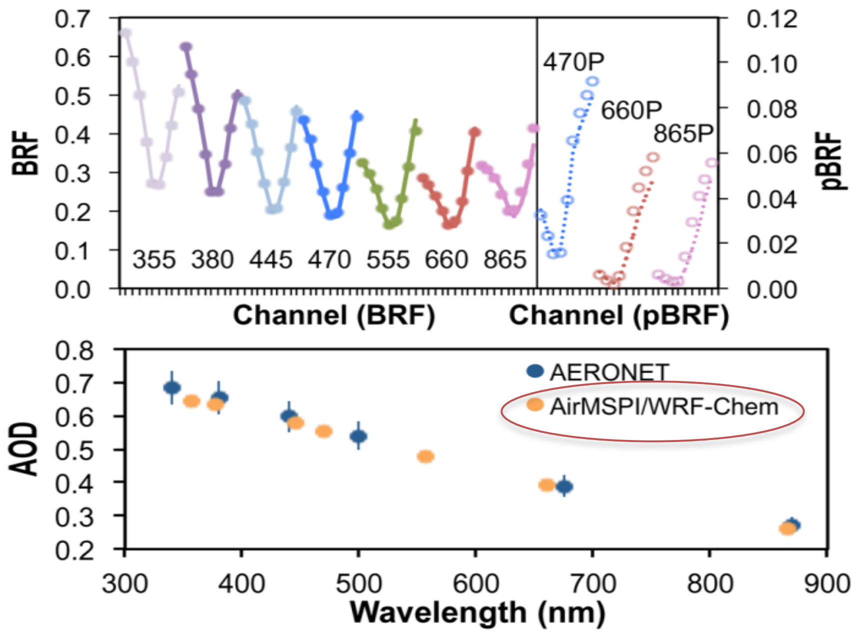
Multispectral nadir imagery over Hanford, CA on 18 Jan. 2013



courtesy of Michael Garay at JPL

Strength of AirMSPI is its high resolution and UV + polarimetric imagery which enhance particle sensitivity





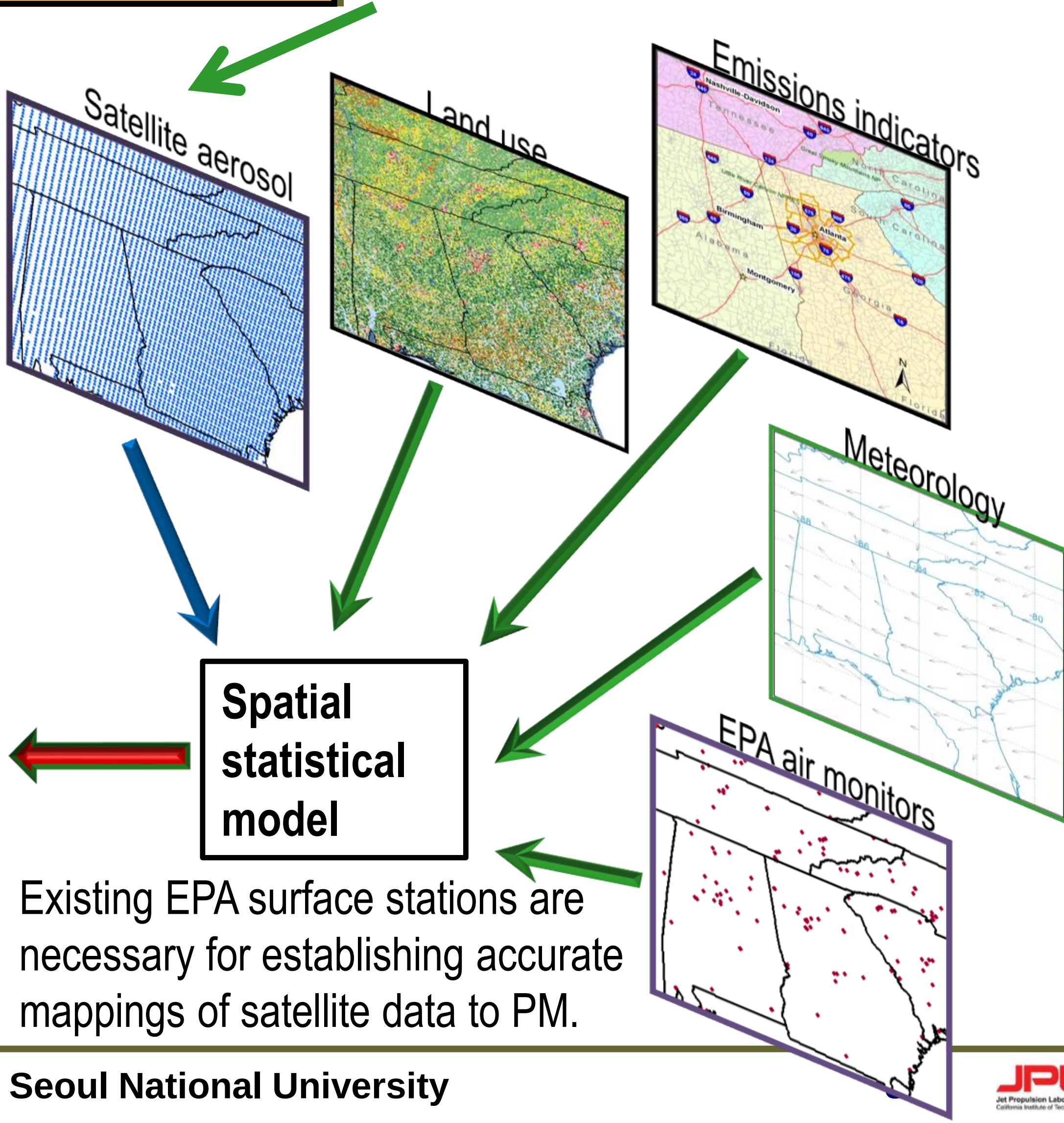
AirMSPI observations over Fresno, January 2012

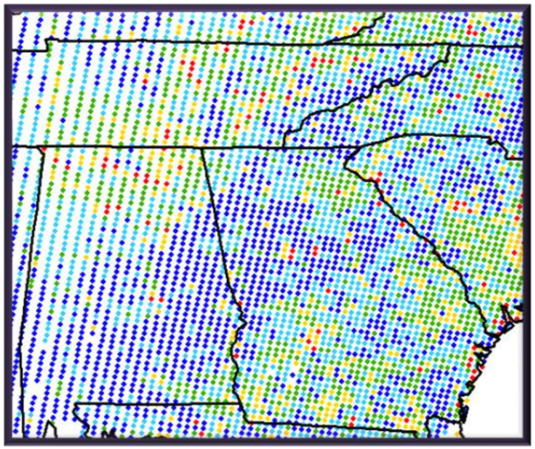
courtesy of Michael Garay at JPL

An *integrated* approach, combining satellites, air quality models, and surface monitors is essential

Chemical transport model provides aerosol vertical profiles to get the boundary layer fraction of total AOD.

Satellite data, meteorology, land use, emissions indicators (e.g., population, traffic information), and EPA measurements are used as inputs to develop a statistical model to predict $PM_{2.5}$ concentration.

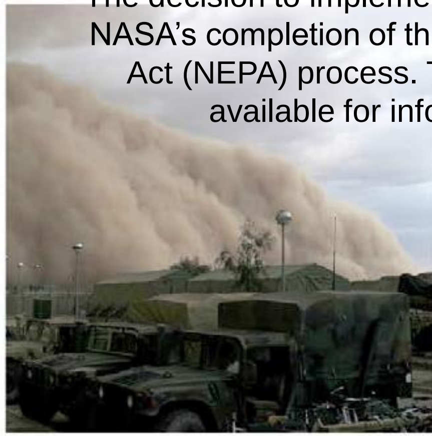




Predicted $PM_{2.5}$

Existing EPA surface stations are necessary for establishing accurate mappings of satellite data to PM.

The decision to implement MAIA will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for information purposes only.



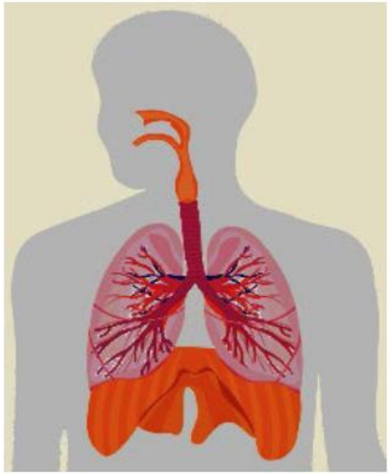
MAIA

Associating airborne particle types with adverse health outcomes

Multi-Angle Imager for Aerosols (MAIA)

The following slides are provided by MAIA PI:
David Diner
JPL

MAIA objective



Coarse particles irritate and inflame our respiratory systems.

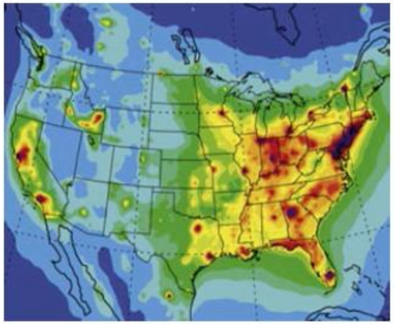
Fine particles penetrate deep into our lungs and carry toxins into our bloodstreams.

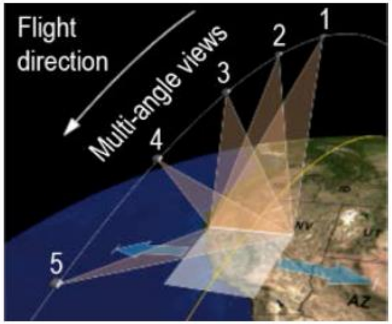
Airborne **particulate matter (PM)** is a well-known cause of cardiovascular and respiratory diseases, heart attacks, low birth weight, lung cancer, and premature death.

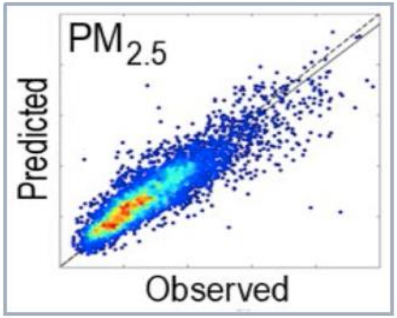
But the relative toxicity of specific **PM types** is poorly understood.

MAIA is designed to fill this gap in our understanding and enable more cost-effective pollution controls and improved health outcomes.

MAIA investigation approach







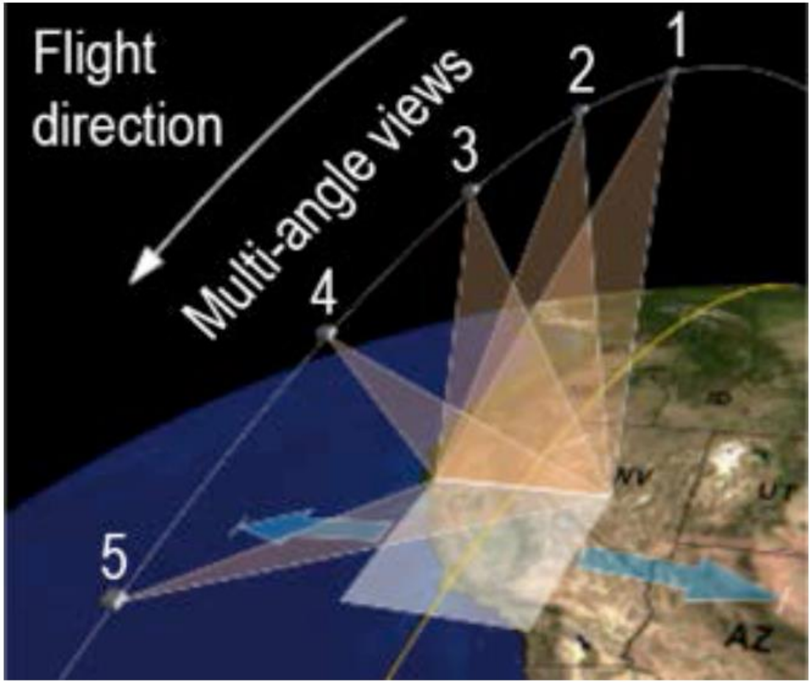
The WRF-Chem chemical transport model (CTM) provides initial estimates of the abundances of different aerosol types, along with their vertical distributions.

The MAIA instrument uses multi-angle and multispectral radiometry and polarimetry to eliminate CTM biases and retrieve fractional aerosol optical depths of different particle types.

Geostatistical models (GSMs) derived from collocated surface and MAIA measurements relate fractional aerosol optical depths to near-surface concen-trations of major PM constituents.

Geocoded birth, death, and hospital records and epidemiological methodologies are used to associate PM exposure with adverse health outcomes.

MAIA cameras are mounted on a 2-axis gimbal for targeted science operations and calibration



Along-track axis provides step-and-stare multiangle imagery (±60º at instrument)

Cross-track axis proves axis to targets off the sub-satellite track (±45º at instrument)